



**International Conference
on Environmental Systems**



In-Flight Performance of the TES Loop Heat Pipe Rejection System – Seven Years In Space

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42nd ICES, 15-19 July 2012, San Diego, California

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Outline

- Brief description of the Tropospheric Emission Spectrometer
- Cryocooler subsystem hardware description
- Cryocooler heat rejection system
- Typical in-orbit performance
- Performance with start-up heater
- Summary



Brief TES Description

- The Tropospheric Emission Spectrometer (TES) is an infrared, high spectral resolution Fourier transform spectrometer with a 3.3 to 15.4 μm wavelength coverage
- TES is a scanning instrument intended for determining the chemical state of the Earth's lower atmosphere (the troposphere) from the surface to 30+km
- TES produces vertical profiles of important pollutant and greenhouse gases such as carbon monoxide, ozone, methane, and water vapor on a global scale every other day
- TES was launched into orbit onboard NASA's Earth Observing System Aura spacecraft on July 15, 2004 from Vandenberg Air Force Base, California

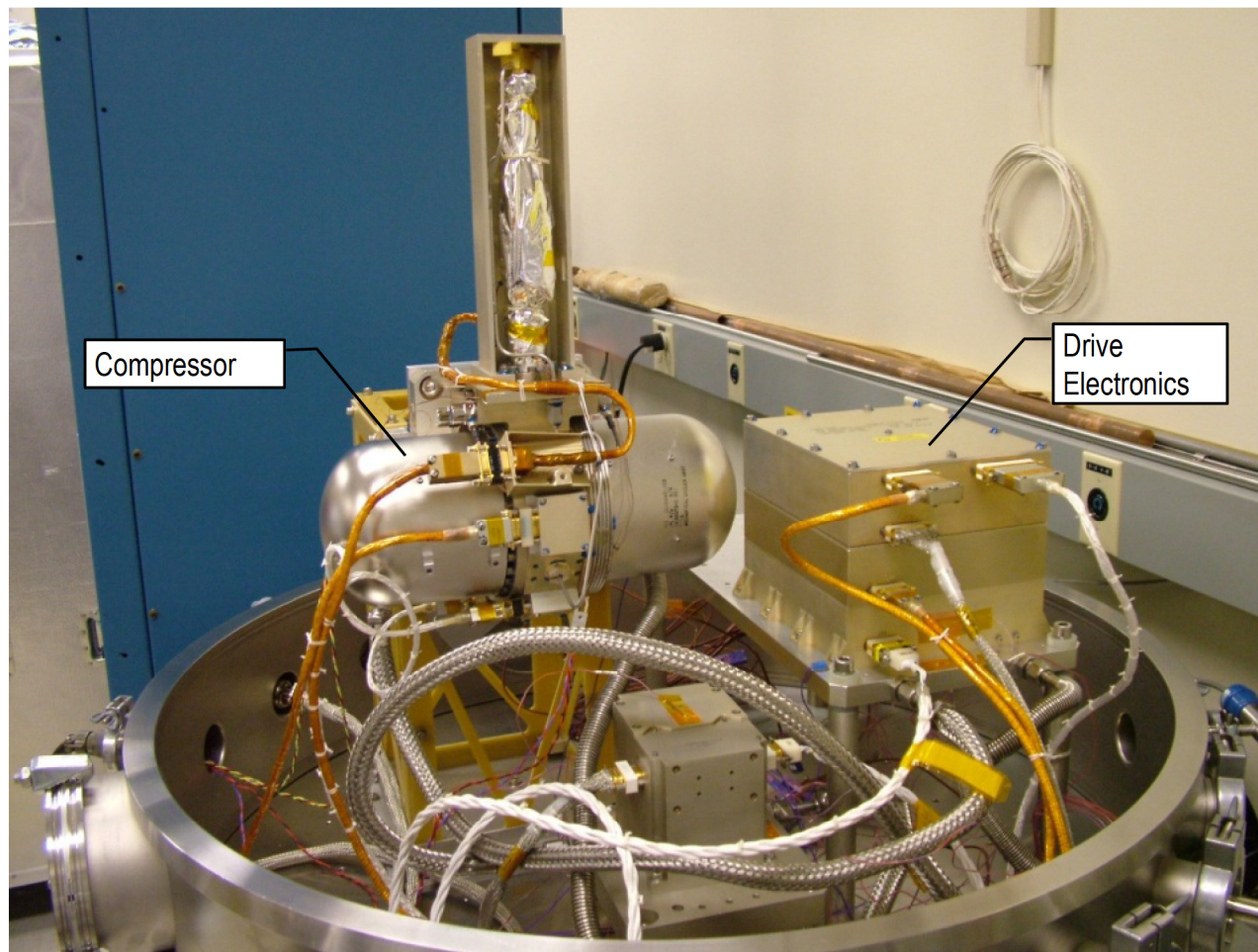


TES Cryogenic Subsystem Design

- The cryogenic subsystem design makes use of active and passive cooling
- A pair of NGAS single-stage pulse tube coolers are used to cool the Mercury Cadmium Telluride (HgCdTe) focal planes to 65K
- Two coolers are required to cool four detectors in two separate focal plane opto-mechanical assemblies separated by about 40cm
- The cooler heat rejection system (HRS) makes use of loop heat pipes (LHPs) and constant conductance heat pipes (CCHPs) to transport the cooler waste heat to the nadir-facing radiators

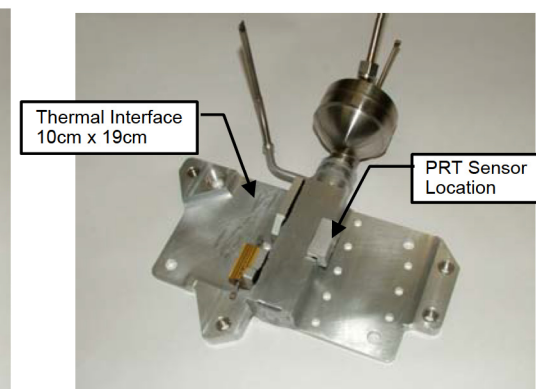
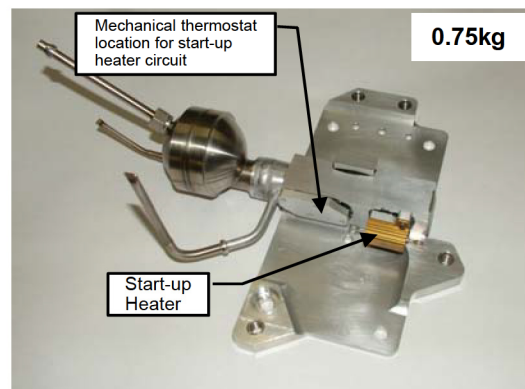
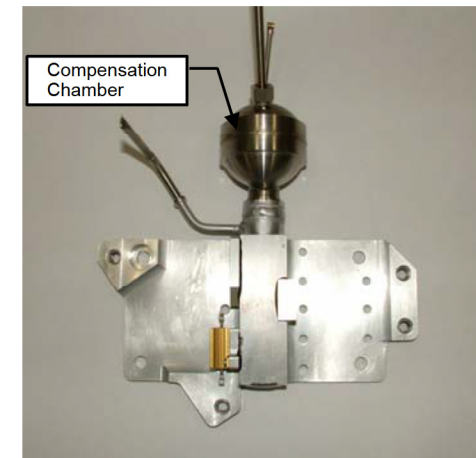
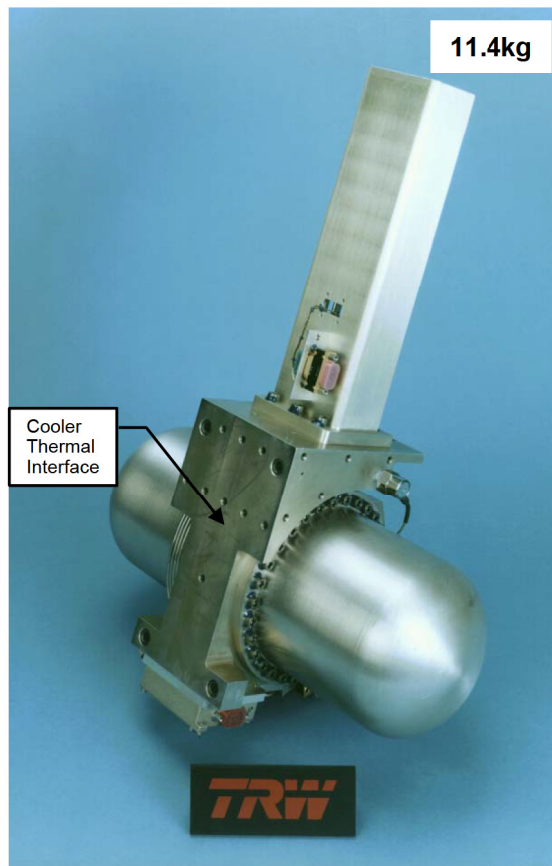


Pulse Tube Cryocooler Subsystem



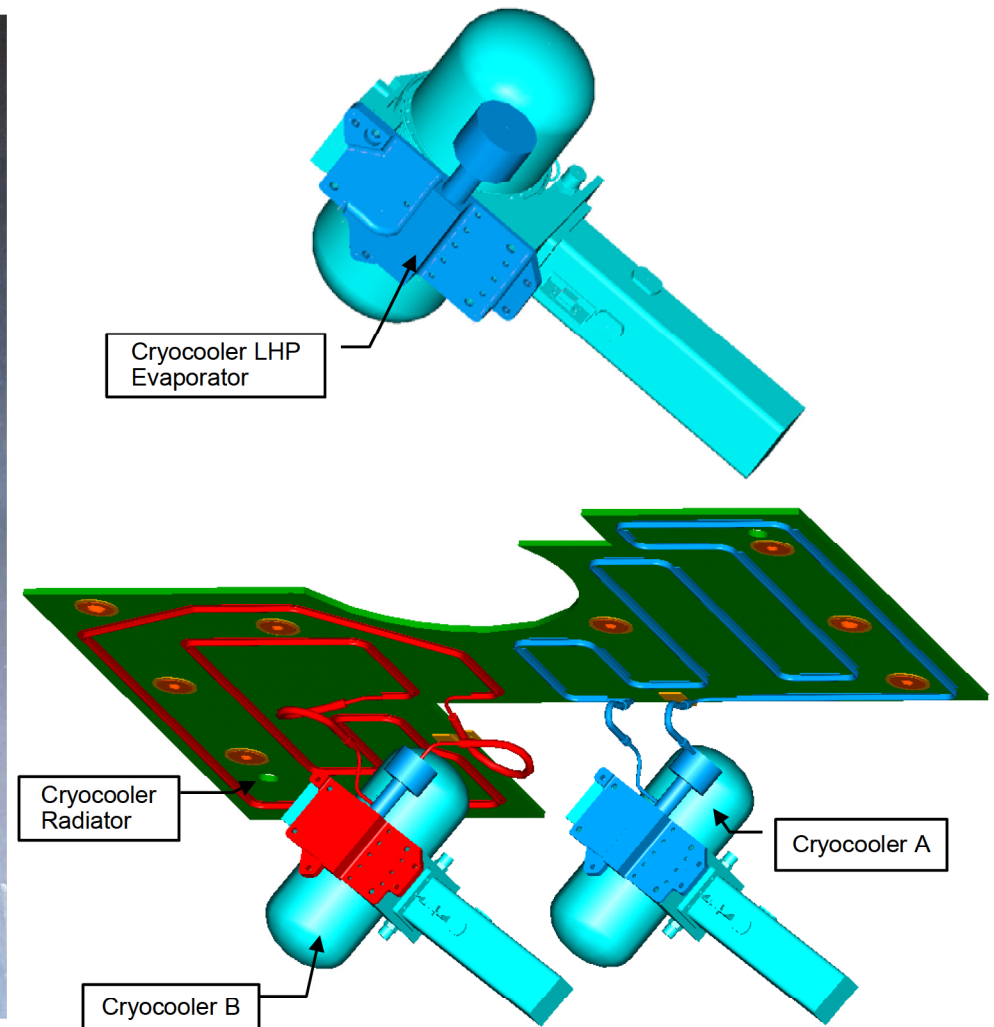
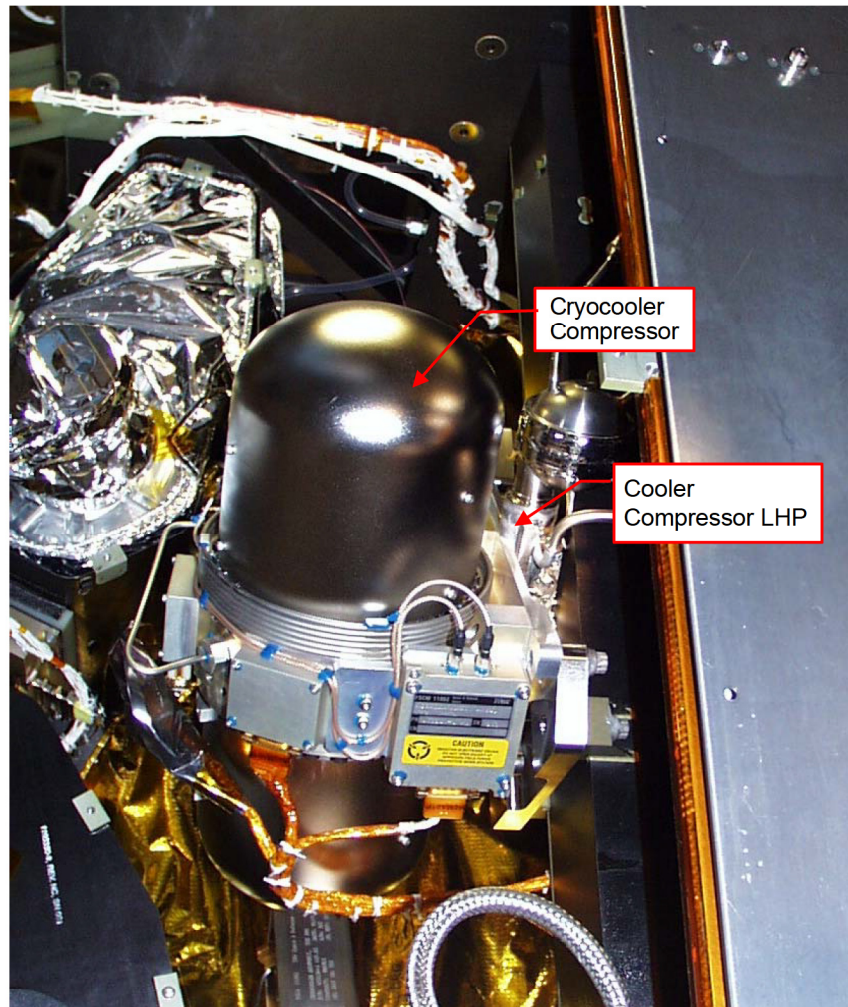


Pulse Tube Cryocooler Subsystem with LHP Evaporator



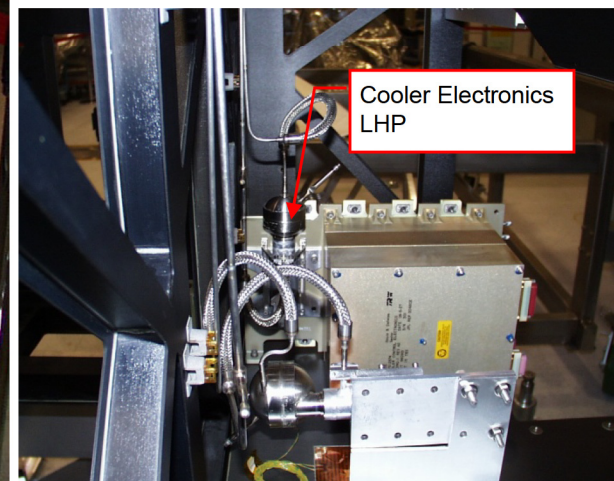
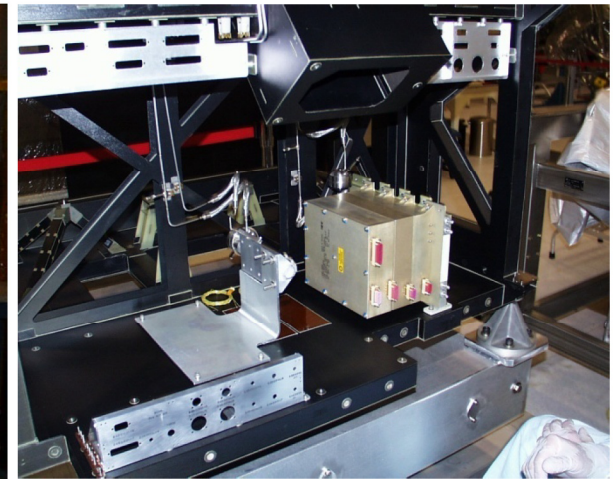
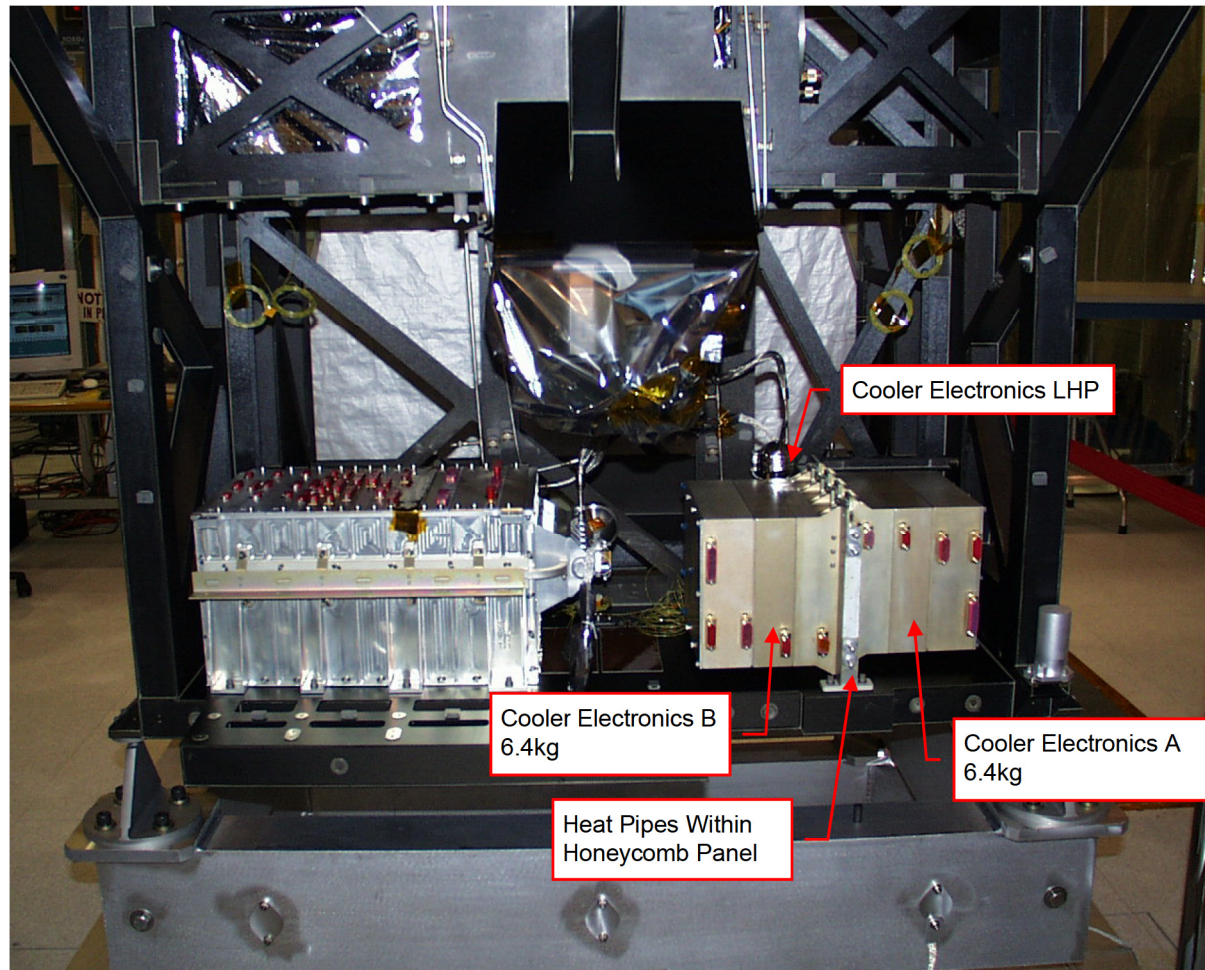


Pulse Tube Cryocooler Subsystem with LHP-based HRS



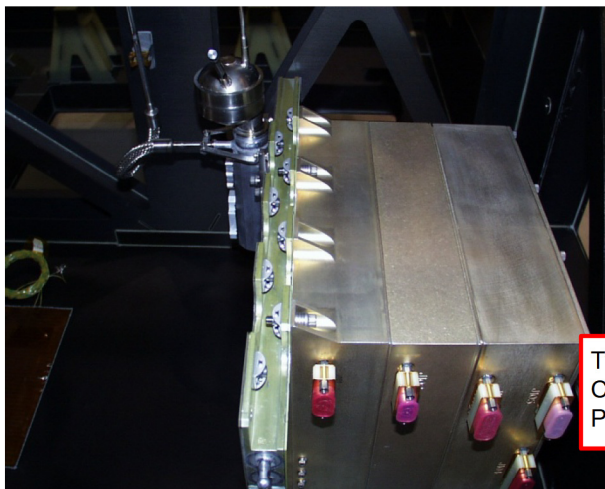
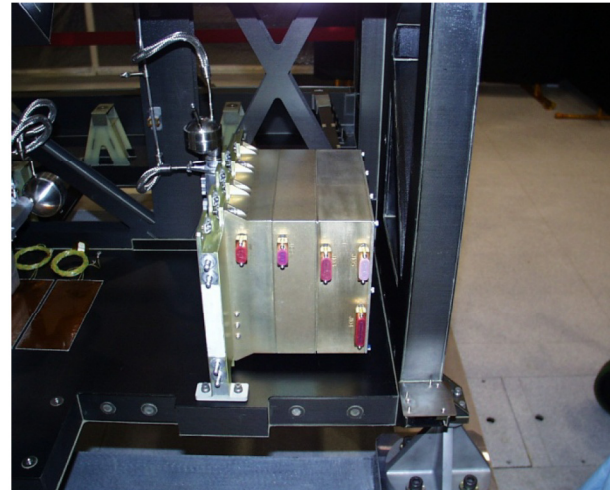
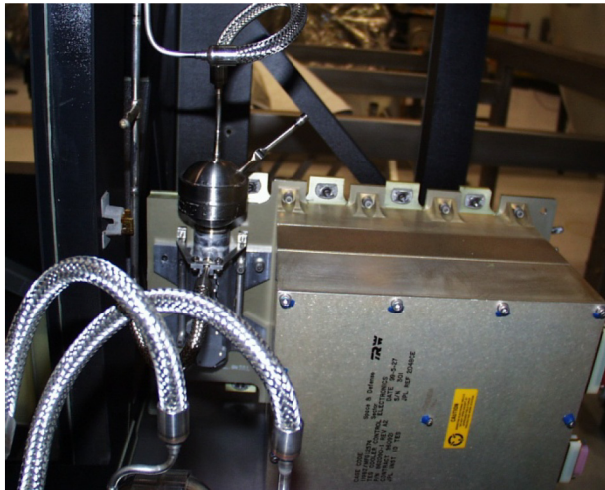


Cooler Heat Rejection System for Cooler Drive Electronics

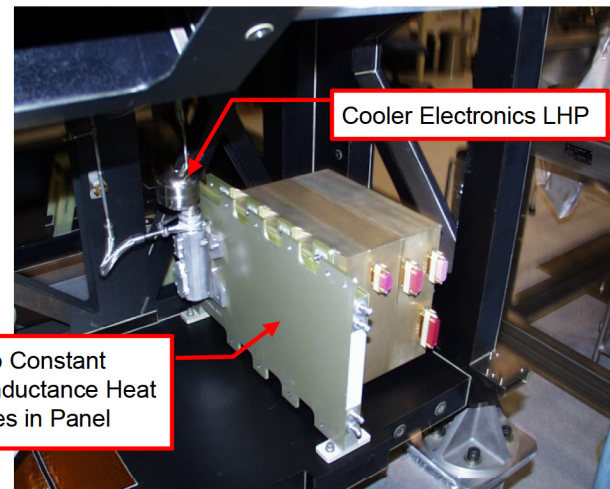




Cooler Heat Rejection System for Cooler Drive Electronics (Cont'd)



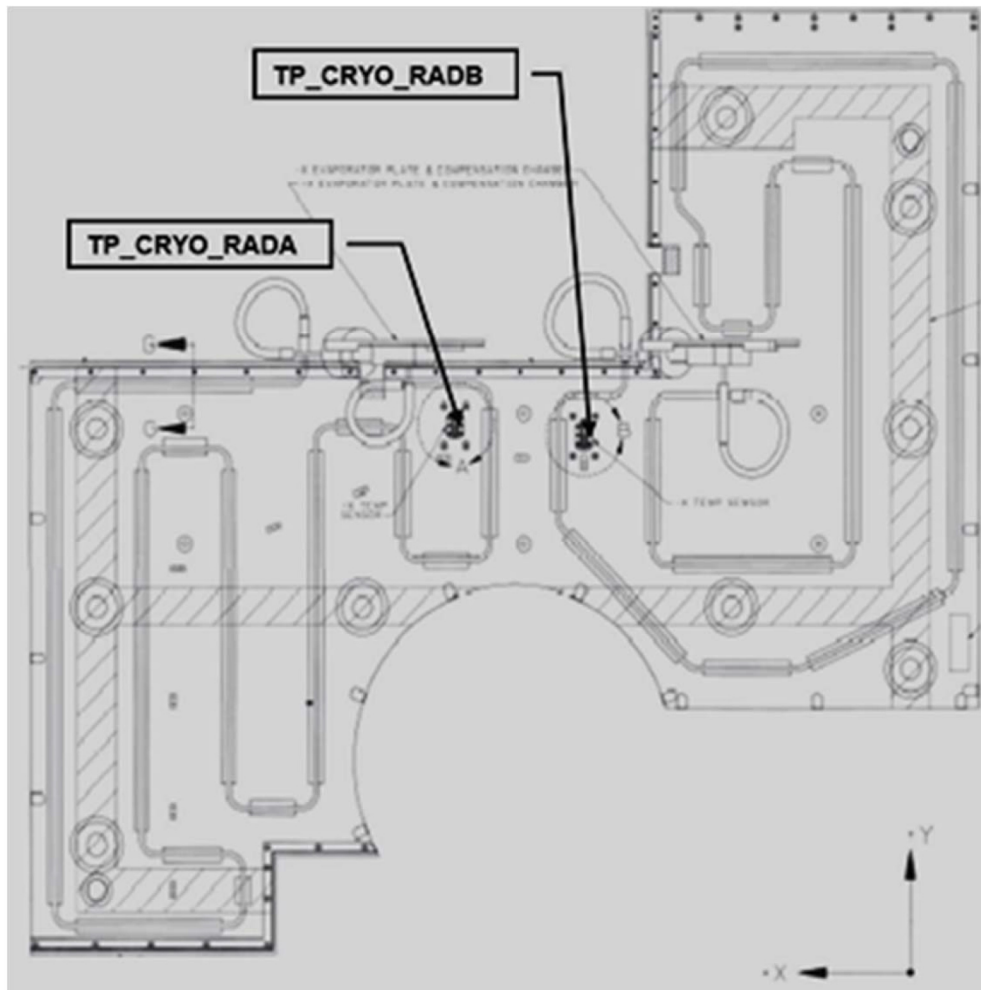
Two Constant Conductance Heat Pipes in Panel



Cooler Electronics LHP



Cooler Heat Rejection System – LHP Condenser





Cooler Heat Rejection System – Cryocooler LHP Radiator





Cryosystem In-orbit Thermal Performance

- Pulse tube coolers:
 - Provide cooling to focal plane arrays at 65K
 - Drive electronics use closed-loop temperature control to maintain cooler coldtip at 63.5K
 - Four HgCdTe focal plane detector arrays are housed in two separate focal plane opto-mechanical assemblies
- Two weeks after launch water-ice contamination on focal planes led to a significant degradation in science data
 - This led to the need for the 1st decontamination cycle
 - A decontamination cycle requires the coolers to be powered off and the focal plane decontamination heaters to be powered on
 - For each decontamination cycle both coolers are turned off and on which requires the cooler LHPs to turn off and on
 - A decontamination cycle is completed in 48-hrs
 - To date 23 decontamination cycles have been performed successfully
 - Decontamination cycles are now performed every 6-months
 - To date the start-up heaters have only been energized 5 times on cooler B LHP



In-Orbit Performance for Typical Decontamination Cycle Data Set for 6-days

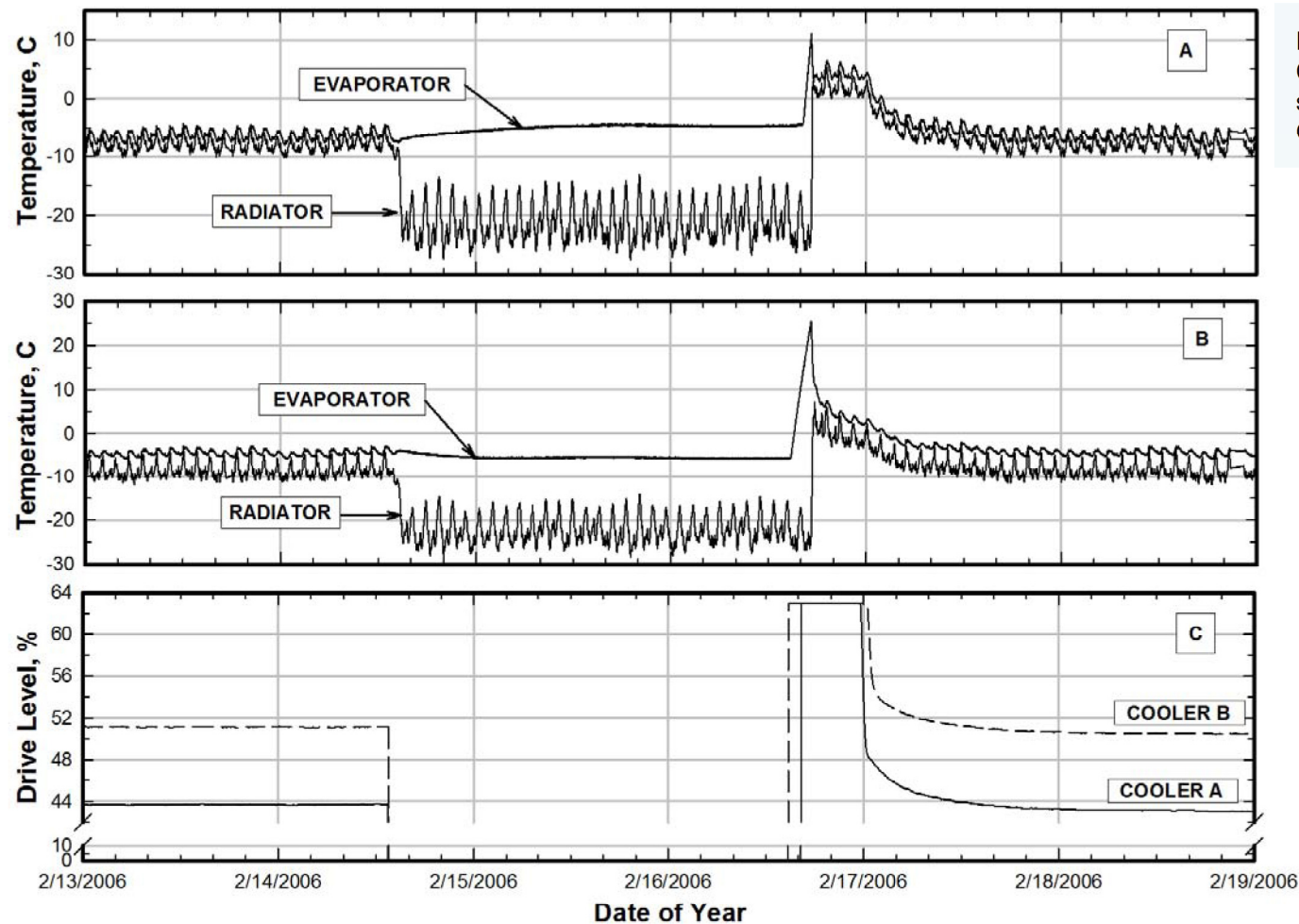


Figure 8. Decontamination cycle 15 - Cryocooler A and B LHP shutdown and startup, A) Cooler A LHP, B) Cooler B LHP, C) Cooler A and B drive levels.



In-Orbit Performance for Typical Decontamination Cycle Data Set for 12-hrs

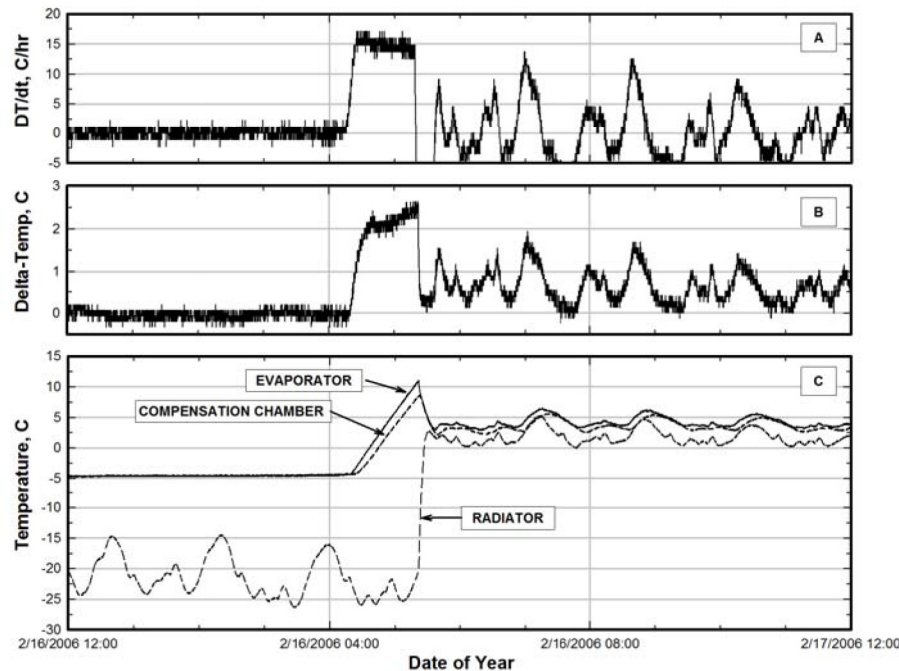


Figure 9. Decontamination cycle 15 - Cryocooler A LHP startup, A) Evaporator temperature rate of change, B) Superheat, C) Evaporator, compensation chamber and associated radiator.

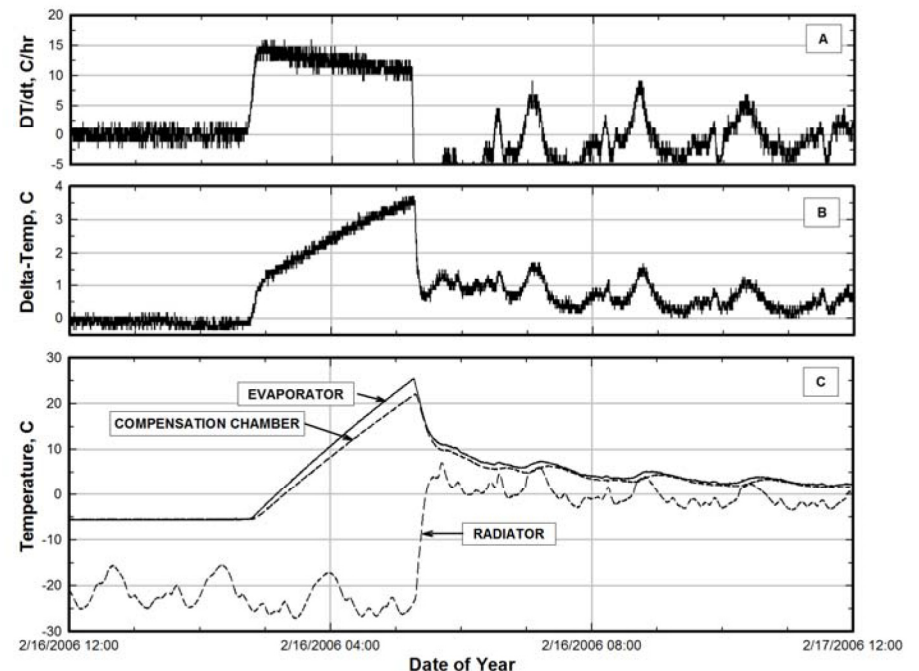


Figure 10. Decontamination cycle 15 - Cryocooler B LHP startup, A) Evaporator temperature rate of change, B) Superheat, C) Evaporator, compensation chamber and associated radiator.



Decontamination Cycle 16 with Features Data Set for 12-hrs

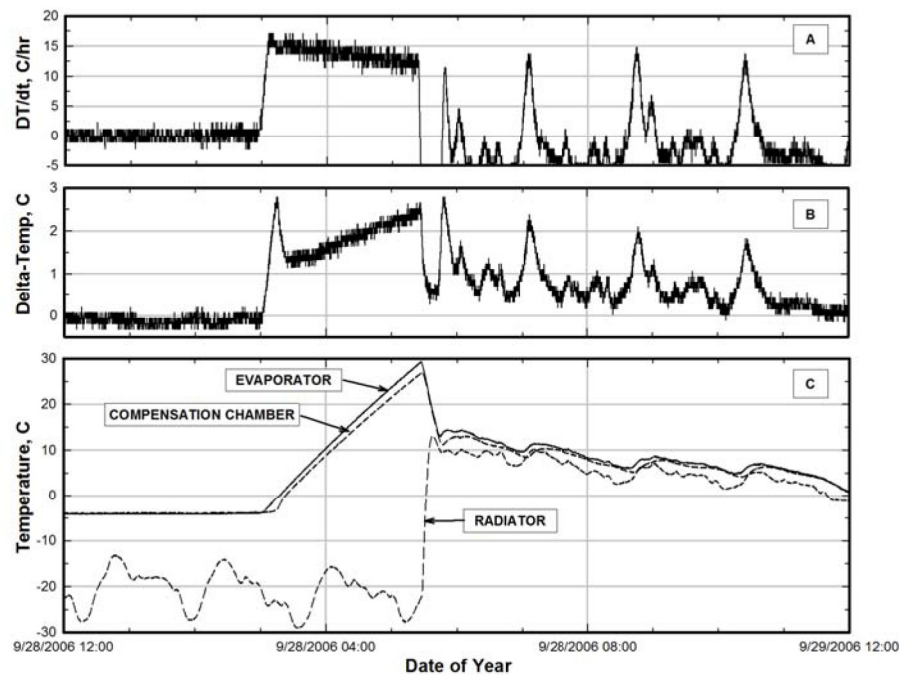


Figure 11. Decontamination cycle 16 - Cryocooler A LHP startup, A) Evaporator temperature rate of change, B) Superheat, C) Evaporator, compensation chamber and associated radiator.

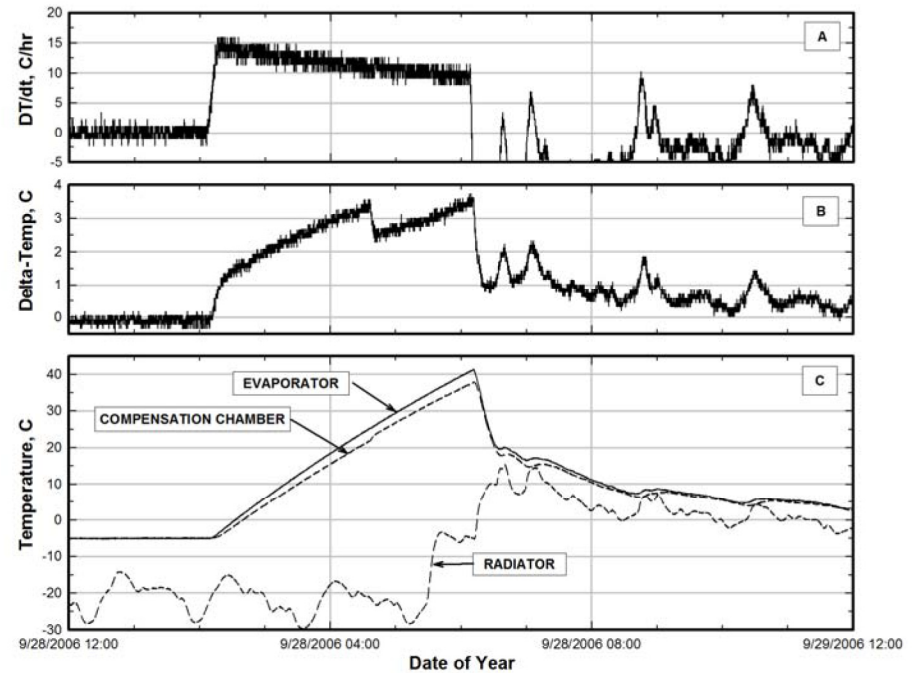


Figure 12. Decontamination cycle 16 - Cryocooler B LHP startup, A) Evaporator temperature rate of change, B) Superheat, C) Evaporator, compensation chamber and associated radiator.



Cooler LHP Theoretical Transient Response on Power-on

- Cryocooler compressor temperature rate of change on power-on
 - Compressor + LHP evaporator is ~12.2kg
 - Power dissipation at 63% drive level is 40.7W for cooler A (37.7W for cooler B)
 - $dT/dt = (40.7\text{J/s}) / [(12.2\text{kg}) \times 840\text{J/kg-C}] = \mathbf{14.3\text{C/hr}}$ for cooler A (14-15C/hr measured)
- Cryocooler electronics temperature rate of change on power-on
 - 2xDrive electronics + LHP evaporator + center plate with two heat pipes is ~15.6kg
 - Power dissipation at 63% drive level is 27.6W
 - $dT/dt = (27.6\text{J/s}) / [(15.6\text{kg}) \times 960\text{J/kg-C}] = \mathbf{6.6\text{C/hr}}$ (5.7C/hr measured)
- Cryocooler LHP evaporator temperature rate of increase after power-on is >2X higher than cooler drive electronics LHP evaporator
- The cooler drive electronics LHP evaporator temperature rate of increase on power-on is the lowest of all 5 LHPs



In-Orbit Performance Summary for Entire Mission

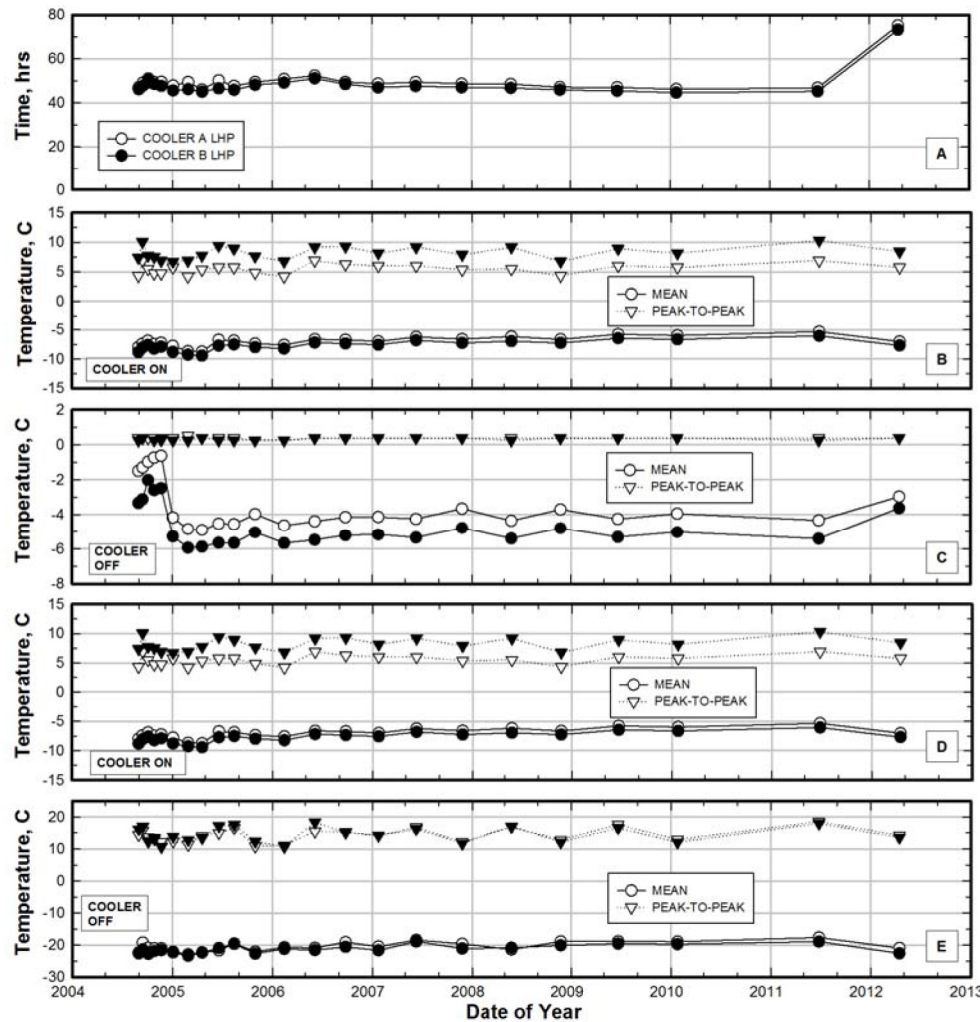


Figure 13. On-orbit data summary for entire mission duration: A) Cryocooler off time duration, B) Evaporator temperature prior to cooler shut-down, C) Evaporator temperature after cooler shut-down, D) Radiator temperature prior to cooler shut-down, E) Radiator temperature after cooler shut-down. Note, the filled-in symbols refer to cooler B LHP.



In-Orbit Performance Summary for Entire Mission (Cont'd)

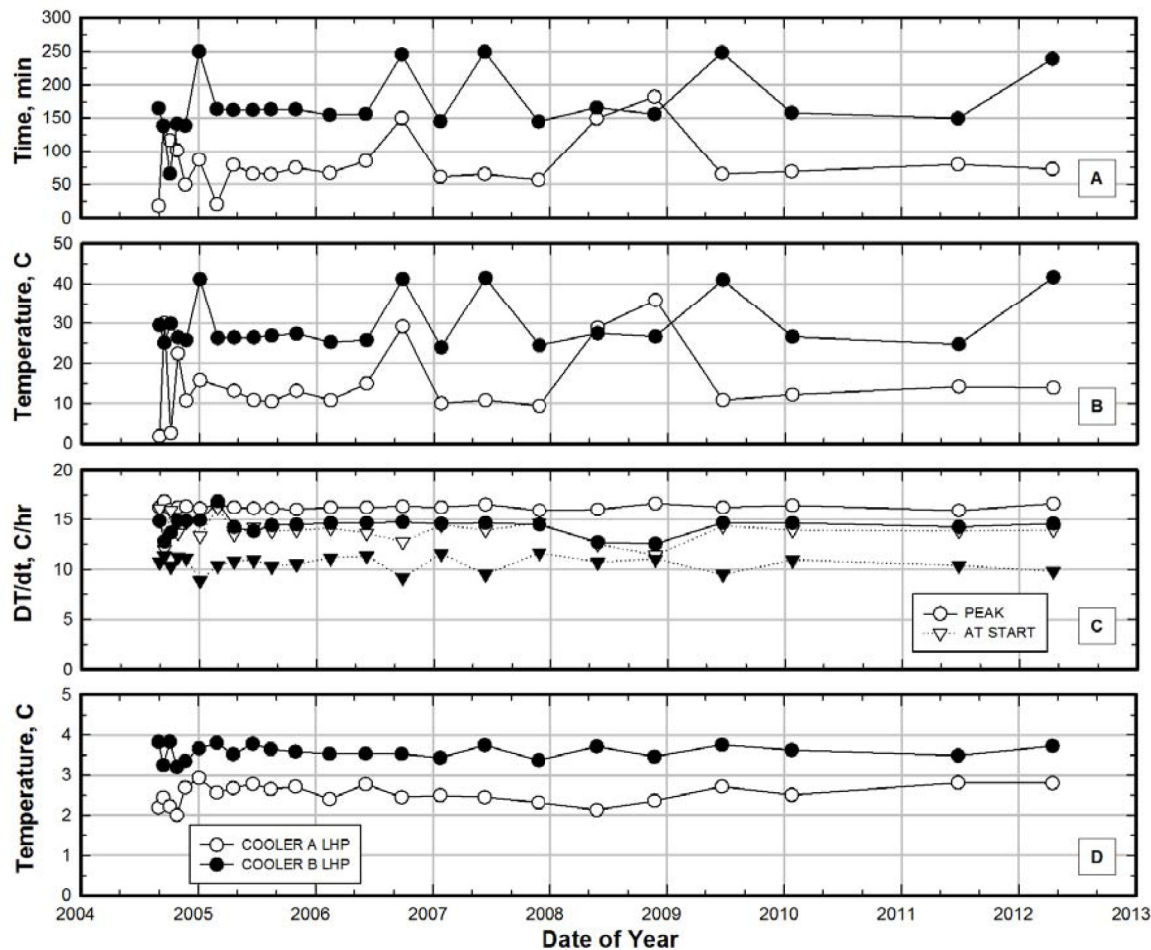


Figure 14. On-orbit data summary for LHP start conditions: A) LHP start time after cooler power on, B) Maximum LHP evaporator temperature at start-up, C) Evaporator temperature rate of change at start-up and peak from cooler power on, D) Superheat at start-up. Note the filled-in symbols refer to cooler B LHP.



Summary

- Water-ice contamination on the detectors led to the need for decontamination cycles which requires the cooler LHPs to turn off and on when power cycling the cryocooler compressors
- All decontamination cycles have been successful due to the thermal design scheme implemented which added start-up heater circuits and bi-metallic thermostats for passive control
- Start-up heaters have been used a total of 5 times by the same LHP with the lowest temperature rate of increase after cryocooler power on
- The LHP-based heat rejection system has performed very well for the entire mission, maintaining the compressors at near 0C and drive electronics near 15C, respectively, with less than a 5C p-p orbital temperature variation
- For almost eight years, the TES instrument has produced exceptional science and is expected to continue for the remainder of the extended 9 year mission

